Tap On, Tap Off:

Onscreen Keyboards & Mobile Password Entry

Kristen Greene
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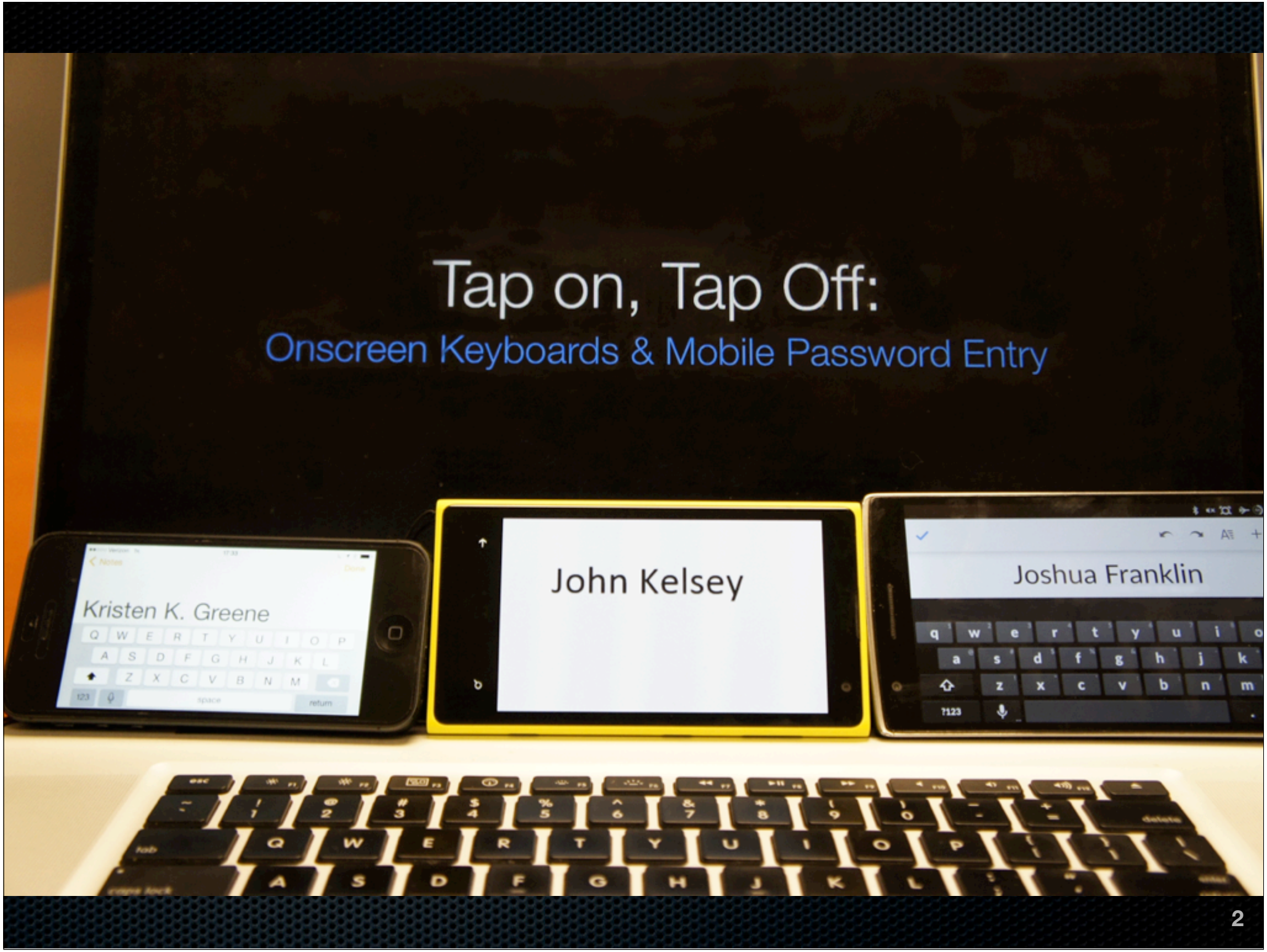
U.S. Department of Commerce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Kristen K. Greene
John Kelsey
Joshua Franklin

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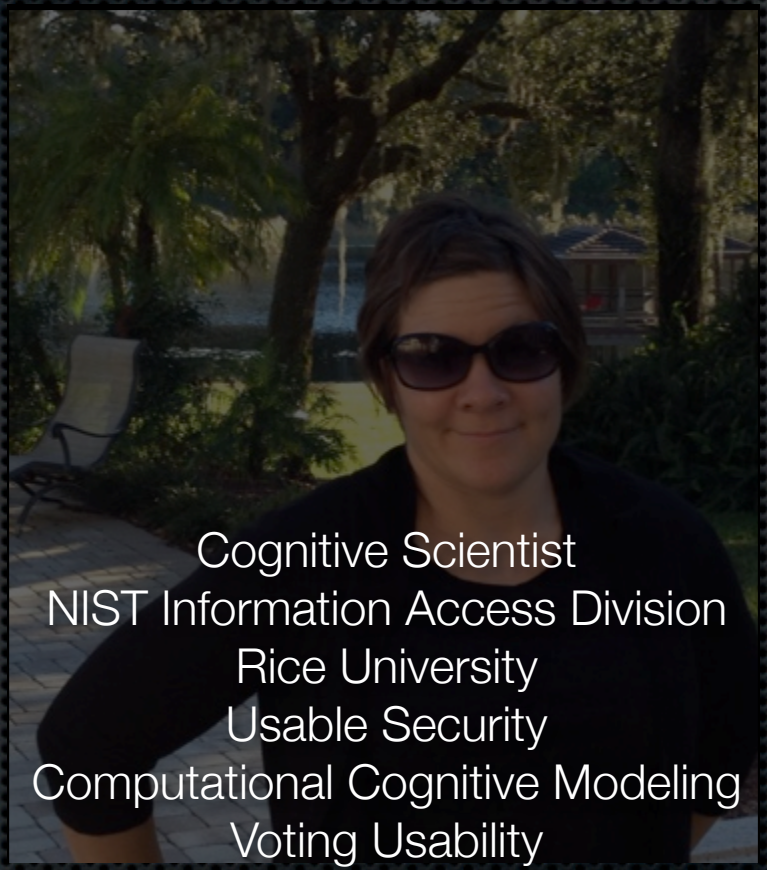
Outline

- Who we are
- Purpose
- Usability background
- Password security background
- Prior work
- Current methodology and results
- Conclusions

Joshua Franklin

Information Security Engineer
NIST Computer Security Division
George Mason University
Cellular Security
Mobile Security
Voting Security

Kristen Greene



Cognitive Scientist
NIST Information Access Division
Rice University
Usable Security
Computational Cognitive Modeling
Voting Usability

John Kelsey

Cryptographer
NIST Computer Security Division
University of Missouri Columbia
Symmetric Cryptography
PRNGs
Voting Security

The Problem

6n04%Ei'Hm3V is 23 taps

EHVnim6043%' is 15 taps

Using Keyboard from Android Lollipop

Purpose

- Explore current state of usability and security metrics for passwords
- Assign strength metrics to passwords for which we already had usability metrics
  - How much entropy is lost as a result of permuting passwords to be easier to enter on mobile devices?

Usability Background

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Usability

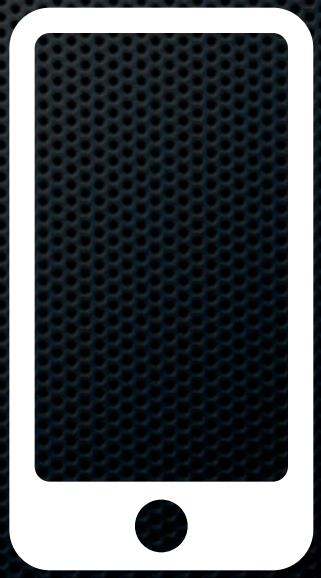
- Context of use
- Effectiveness
- Efficiency
- Satisfaction

Usability: ISO 9241

- “The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.”

Usability: Context of Use

- “Users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used.” [ISO 9241]
  - Mobile vs. desktop context



Usability: Effectiveness

- “Accuracy and completeness with which users achieve specified goals.” [ISO 9241]
- Generally measured via **error rates**
  - Password entry errors

Usability: Efficiency

- “Resources expended in relation to the accuracy and completeness with which users achieve specified goals.” [ISO 9241]
- Generally measured via **time on task**
  - Password entry time
  - Number of keystrokes (taps)

Usability: Satisfaction

- “Freedom from discomfort, and positive attitudes towards the use of the product.” [ISO 9241]
- Generally measured via standardized or customized questionnaires

Usability & Security Parallels

- Confidentiality
- Integrity
- Availability
- Effectiveness
- Efficiency
- Satisfaction

Password Security Background

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Attacks on Passwords

- Password guessing
  - Brute force
  - Intelligent guessing

} *We are only concerned with these classes of attacks*

- Eavesdropping
- Social Engineering
- Physical attacks

Password Strength

- Password strength is often expressed in terms of entropy
  - *Note: Entropy is at most only loosely related to the use of the term in thermodynamics.*
- Entropy was originally defined by Claude Shannon in the 1950s

Password Metric Groups

- Two password metric groups
- Classified by how a password is created
  - **user generated** passwords
  - **system generated** passwords (a.k.a. randomly generated)
- Password metrics measure only one of these groups

Randomly Generated Password Metrics

- Shannon entropy formula: $H = \log_2 (B^L)$
  - H = total entropy
  - B = number of characters to choose from
  - L = password length
- [Kuo, 2006] uses modified Shannon entropy

Shannon Entropy Examples

Password	Entropy Estimate
5c2'Qe	39.33
3.bH1o	39.33
a7t?C2#	45.88
m3)61fHw	52.44
p4d46*3TxY	65.55
q80<U/C2mv	65.55
d51)u4;X3wrf	78.66
6n04%Ei'Hm3V	78.66
m#o)fp^2aRf207	91.76
4i_55fQ$2Mnh30	91.76

User Generated Password Metrics

- “Guessing entropy”
  - Estimate of the average amount of work required to guess the password of a selected user
  - Uses Shannon entropy as a foundation
  - “Measures” password strength based on a ruleset

User Generated Password Metrics

- “Min-entropy”
  - Difficulty of guessing the easiest single password to guess in the population
  - NIST specifies dictionary tests and password histories as heuristics to ensure at least 10 bits of entropy

800-63 Entropy Heuristic

- From NIST SP 800-63-2:
  - 1st character = 4 bits per character
  - 2nd thru 8th = 2 bits per character
  - 9th thru 20th = 1.5 bits per character
  - 21+ = 1 bit per character
  - Upper + lower + non-alphabetic = 6 bit bonus
  - Dictionary check = 6 bit bonus

800-63 Min-Entropy Ruleset

- Search a dictionary of at least 50,000 words for the password
  - If found, reject password
- Passwords that are detectable permutations of the username are not allowed

Our Research & Results

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Prior Work

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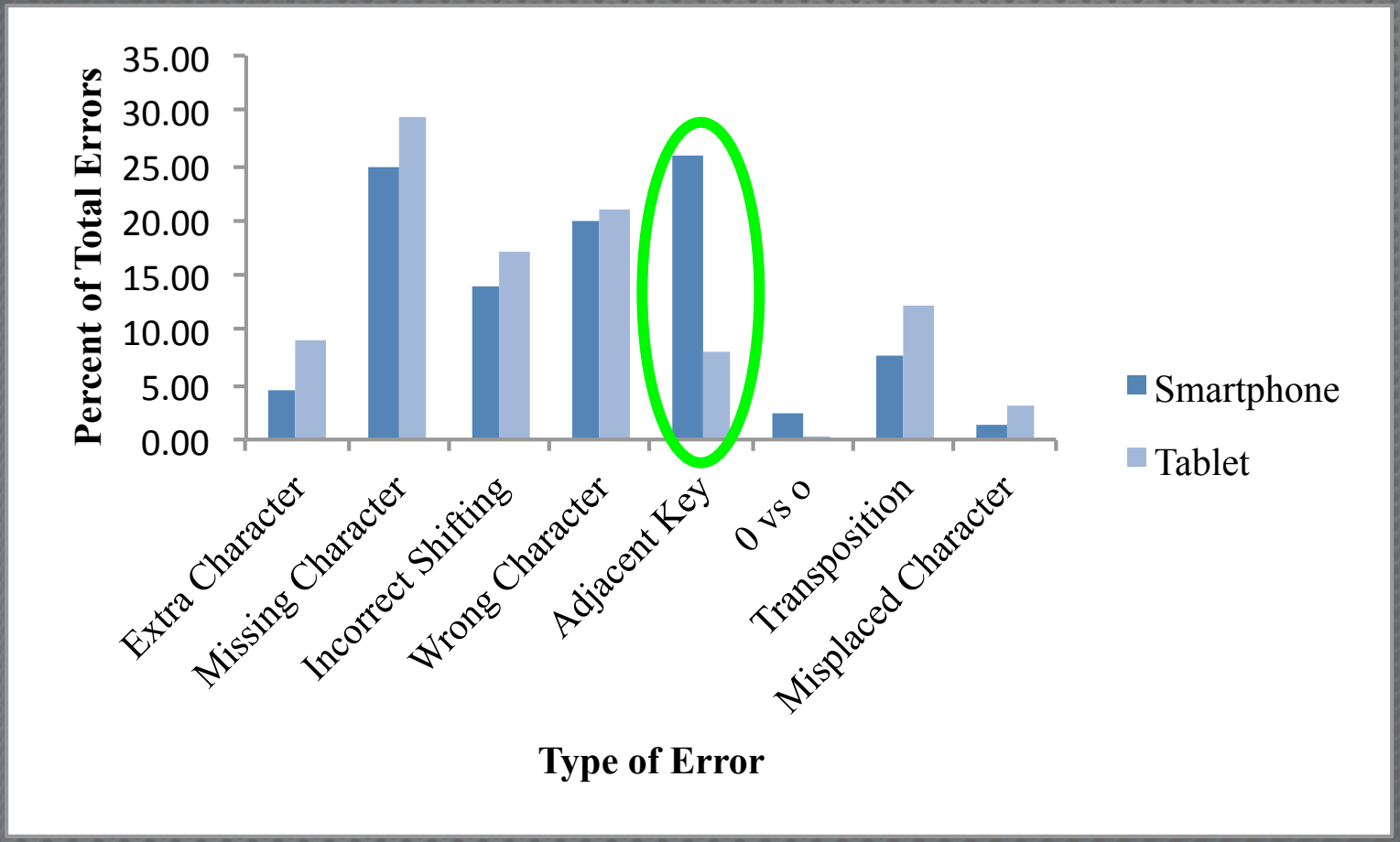
Prior Work

- Recent behavioral study on mobile password entry
- Participants had to learn, input, and recall 10 random passwords
- Onscreen keyboard switching significantly increased input time and introduced errors [Greene, Gallagher, Stanton, & Lee, 2014]

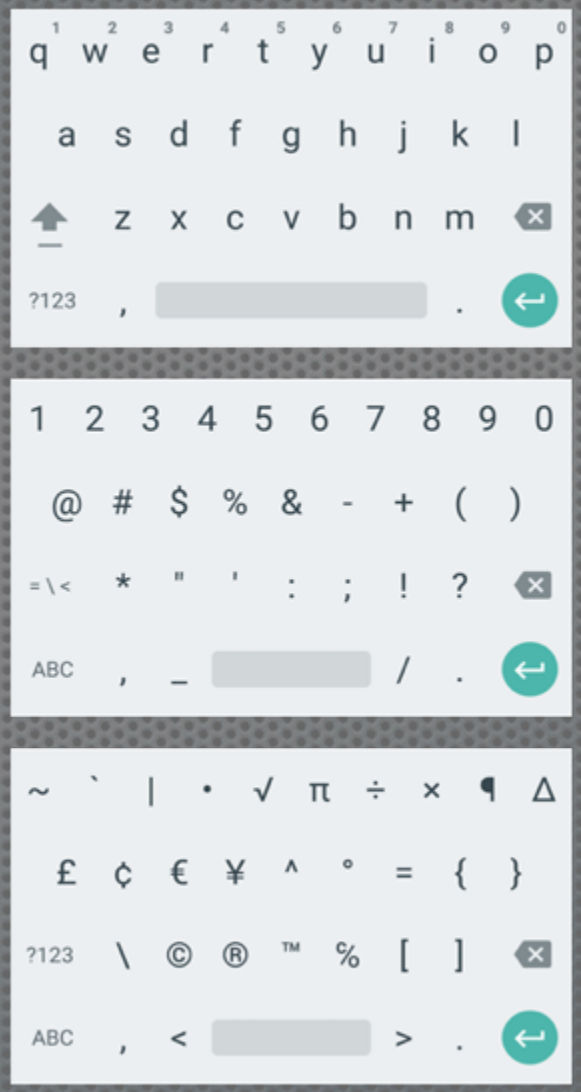
Measurement Granularity

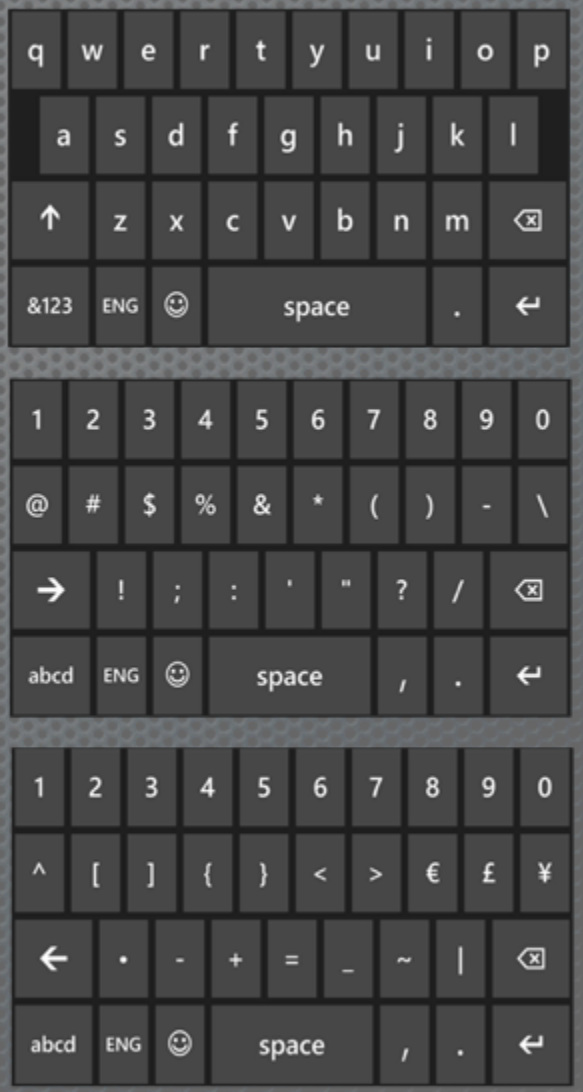
- **Password level**
  - The entire password is either accepted or fails
- **Character level**
  - Multiple types of character errors (e.g., transposition, deletion, substitution)
- Important to look at the nature and number of errors users make when inputting passwords

Tiny Keyboards = More Errors

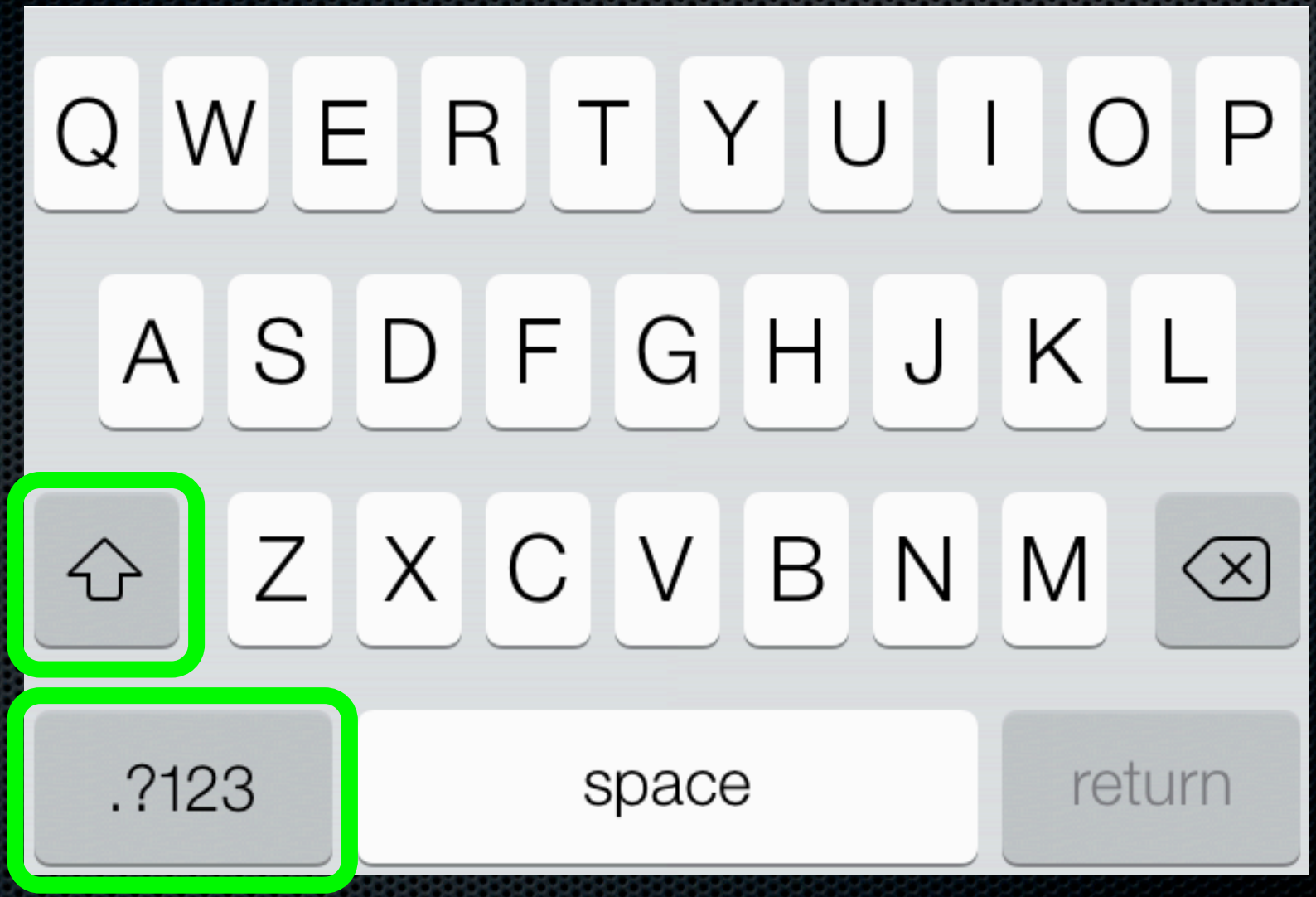


Onscreen Keyboards

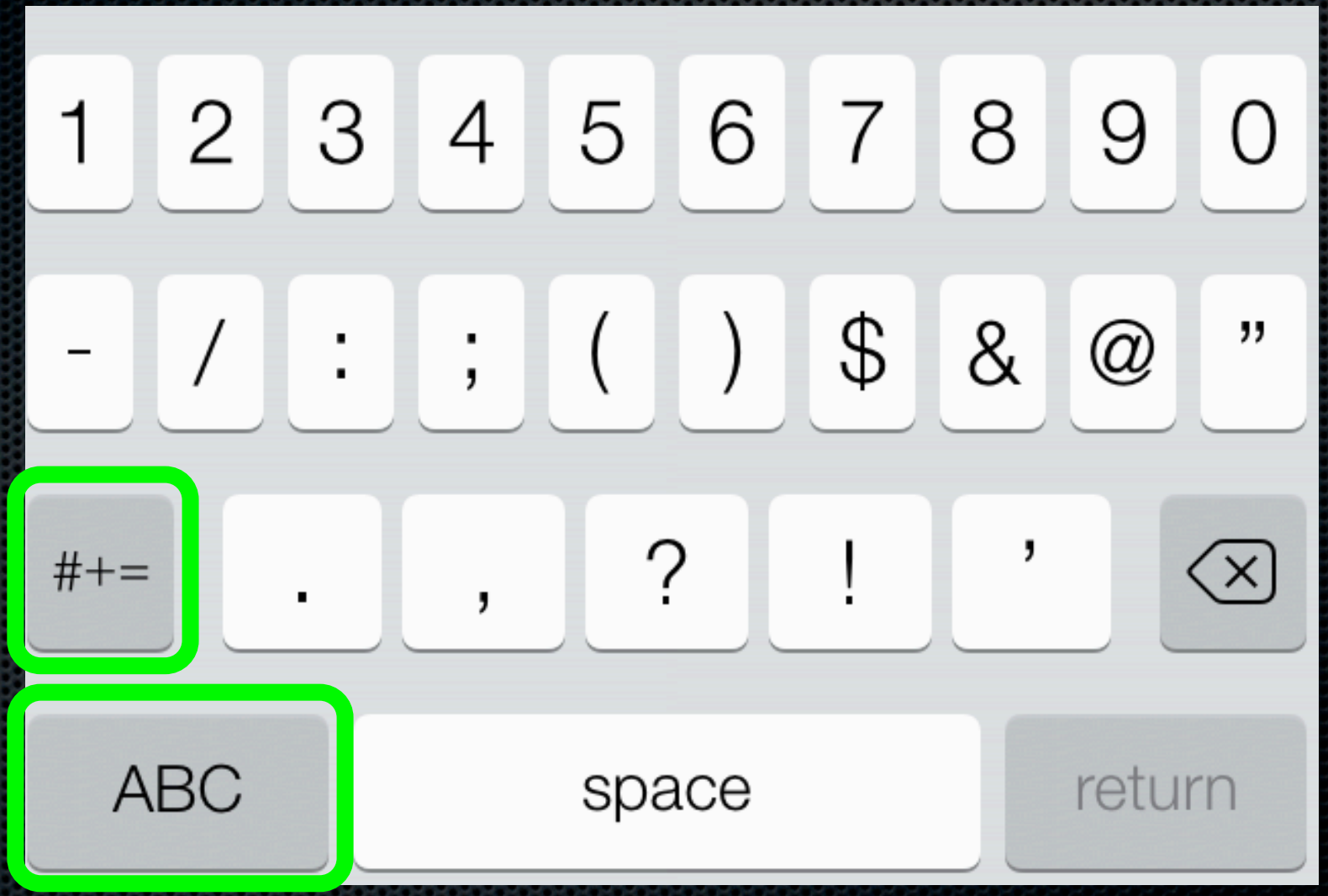




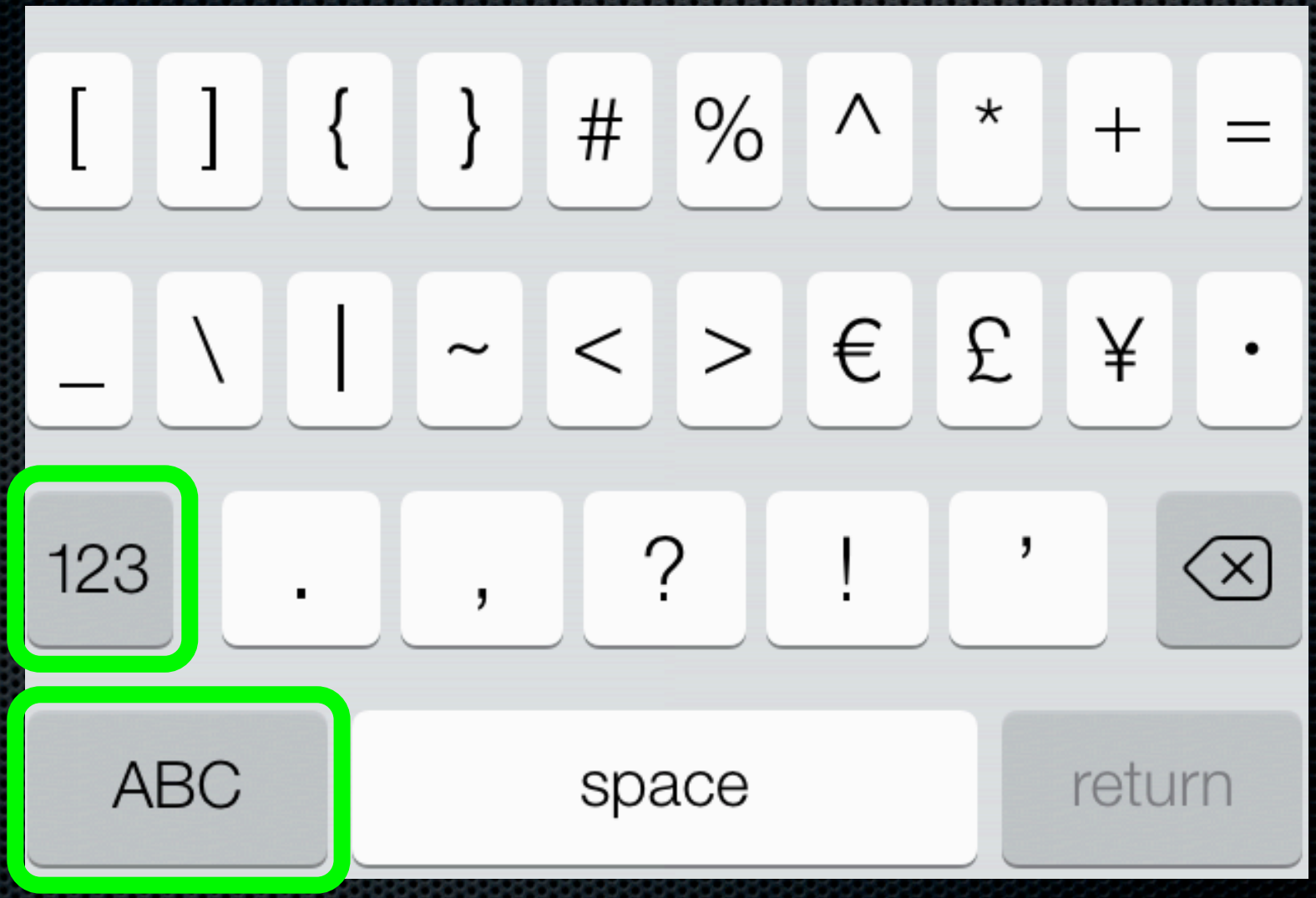
Screen Depth 1



Screen Depth 2



Screen Depth 3



Current Work

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Methodology

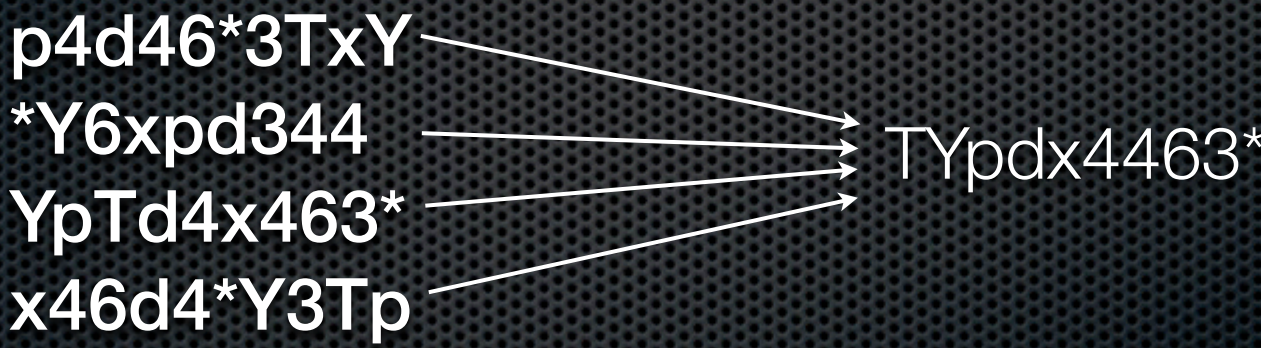
- Defined a **password permutation**
  - Divided characters in password into “classes”
  - Uppercase (U), lowercase (L), numbers (N), and symbols (S)
  - Group similar characters together
- Example:
  - 5c2'Qe is permuted to Qce52'

Permutation and Tap Counts

Original Password	Permuted Password	Length	Taps: Original, Permuted	Keyboard Changes: Original, Permuted	Taps Saved
5c2'Qe	Qce52'	6	11, 8	4, 1	3
m3)61fHw	Hmfw361)	8	11, 10	2, 1	1
q80<U/C2mv	UCqmv802</	10	19, 15	7, 3	4
6n04%Ei'Hm3V	EHVnim6043%'	12	24, 17	9, 2	7
m#o)fp^2aRf207	Rmofpaf2207#)^	14	24, 19	10, 4	6

Password Collisions

- Multiple unique passwords can permute to the same password:



Our Results

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Experiment 1: Fan-Out

How many passwords collide with the same user-friendly password?

How Many Collisions?

Length	10th Percentile	90th Percentile	Average
6	120	180	159
8	840	1680	1329
10	5040	25200	12659
12	27720	277200	132492
14	360360	3153150	1438513
16	2402400	40360320	17187712
18	24504480	514594080	208414540
20	221707200	6518191680	2327087101

Experiment 2: Entropy Loss

How much entropy is lost by permuting passwords?

How Much Entropy Is Lost?

Length	10th Percentile	90th Percentile	Average	Additional Letters
6	6.9	7.5	7.3	2
8	9.7	10.7	10.4	3
10	12.3	14.6	13.6	3
12	14.8	18.1	17.0	4
14	18.0	21.6	20.4	5
16	21.5	25.0	24.0	6
18	24.5	28.9	27.6	6
20	27.9	32.6	31.2	7

Experiment 3: All-Lowercase

How much additional password length would we need to just change over to all lowercase letters?

What About All Lowercase?

Complex Password	All-Lowercase	Extra Letters
6	9	3
8	12	4
10	14	4
12	17	5
14	20	6
16	23	7
18	25	7
20	28	8

q80<U/C2mv

vs

dmstpjnwqiwqok

Unholster your phones and type this:

m#o)fp^2aRf207

Now type this:

Rmofpaf2207#)^

Recap

- Entering complex passwords on mobile devices is difficult
- Our password permutation makes it easier
  - We precisely measure the security loss
  - Fixed by adding a couple extra characters

Conclusions

- **Device constraints matter**
- Old password policies play badly with new devices
- Both usability and security must be considered

Code

- https://github.com/usnistgov/PasswordMetrics
- https://github.com/usnistgov/DataVis

Questions?

- For additional research, visit NIST's Information Technology Laboratory:
  - Kristen Greene
    Information Access Division
    nist.gov/itl/iad
  - John Kelsey
    Joshua Franklin
    Computer Security Division
    csrc.nist.gov

Acknowledgements

- Cathryn Ploehn
- Andrew Rukhin
- Jim Filliben

References

[Greene, Gallagher, Stanton, & Lee, 2014] I Can't Type That! P@$$w0rd Entry on Mobile Devices. In Human Aspects of Information Security, Privacy, and Trust, Lecture Notes in Computer Science Volume 8533, 2014, pp 160-171.

[Stanton & Greene, 2014] Character strings, memory, and passwords: What a recall study can tell us. In Human Aspects of Information Security, Privacy, and Trust, pp 195-206.

[ISO 9241] Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 11: Guidance on usability.

[Kuo, 2006] Human Selection of Mnemonic Phrase-based Passwords, CUPS 2006.

[NIST SP 800-63-2] Burr et al, Electronic Authentication Guideline, National Institute of Standards and Technology, 2013.

[Shannon, 1948] C. E. Shannon, "A mathematical Theory of Communication, 1948.

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Extras

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Data Viz Tool

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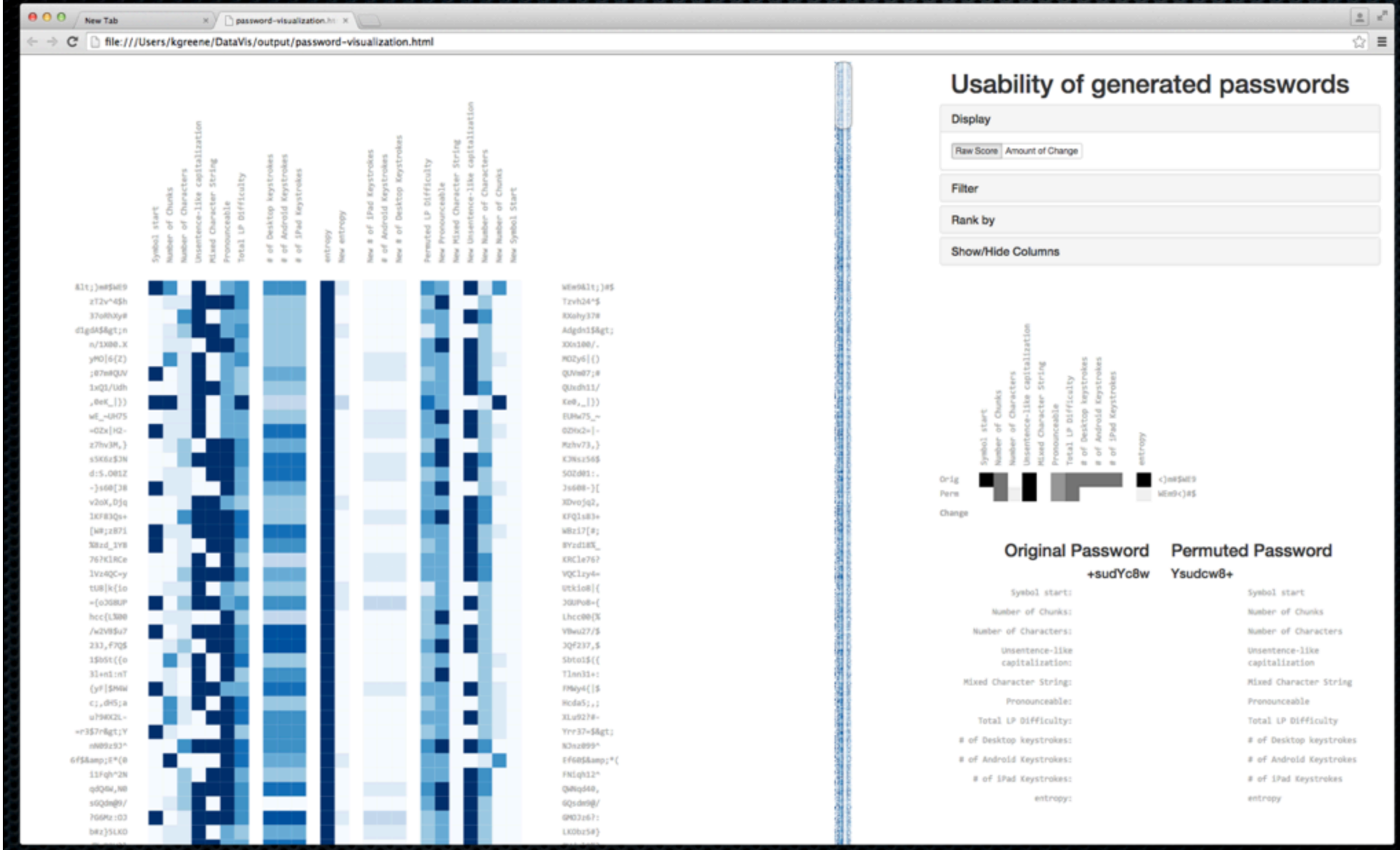
Prior NIST Tool

- Cathryn Ploehn's SURF (Summer Undergraduate Research Fellowship) project
- Shows usability and security metrics side-by-side for original and permuted passwords
- Multiple levels of granularity
- Filtering options
- https://github.com/usnistgov/DataVis


New Tab
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file:///Users/kgreene/DataVis/output/password-visualization.html
Usability of generated passwords
Display
Raw Score
Amount of Change
Filter
Rank by
Show/Hide Columns
Symbol start
Number of Chunks
Number of Characters
Unsentence-like capitalization
Mixed Character String
Pronounceable
Total LP Difficulty
# of Desktop keystrokes
# of Android Keystrokes
# of iPad Keystrokes
entropy
New # of iPad Keystrokes
New # of Android Keystrokes
New # of Desktop Keystrokes
Permuted LP Difficulty
New Pronounceable
New Mixed Character String
New Unsentence-like capitalization
New Number of Characters
New Number of Chunks
New Symbol Start
Orig
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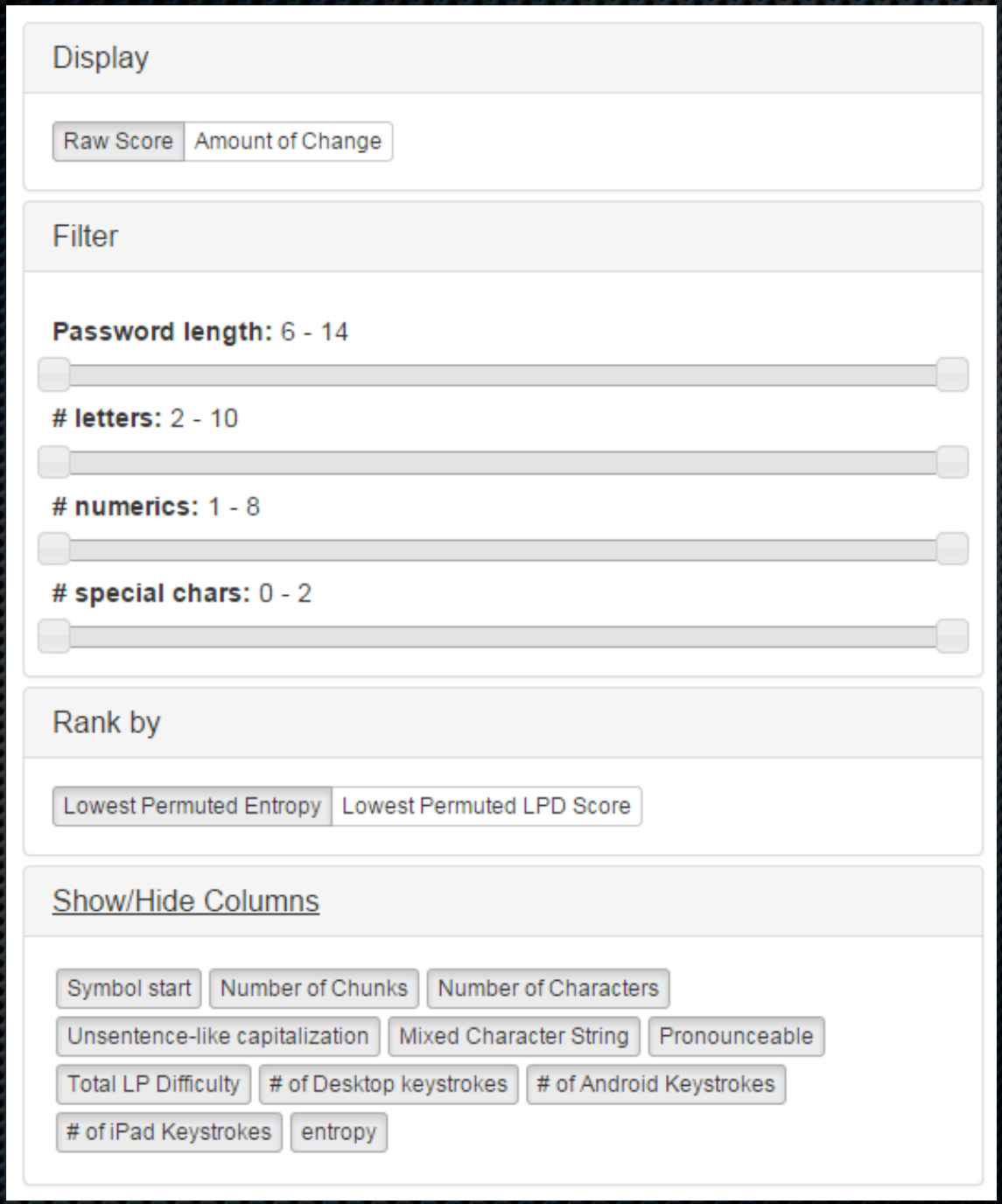
Change
Original Password
+sudYc8w
Permuted Password
Ysudcw8+
Symbol start:
Number of Chunks:
Number of Characters:
Unsentence-like capitalization:
Mixed Character String:
Pronounceable:
Total LP Difficulty:
# of Desktop keystrokes:
# of Android Keystrokes:
# of iPad Keystrokes:
entropy:


Display
Raw Score
Amount of Change
Filter
Password length: 6 - 14
letters: 2 - 10
numerics: 1 - 8
special chars: 0 - 2
Rank by
Lowest Permuted Entropy
Lowest Permuted LPD Score
Show/Hide Columns
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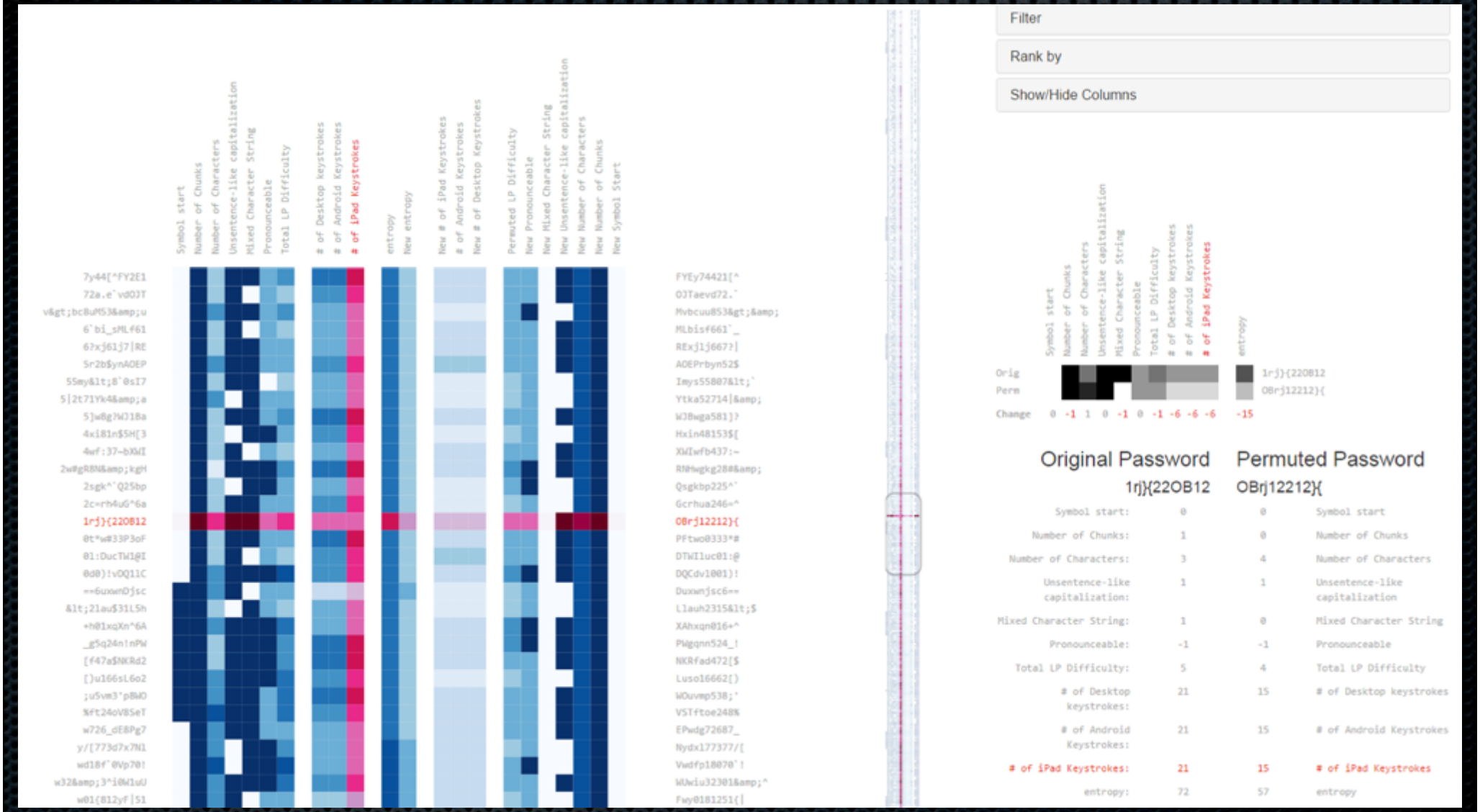
Mixed Character String
Pronounceable
Total LP Difficulty
# of Desktop keystrokes
# of Android Keystrokes
# of iPad Keystrokes
entropy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Permuted LP Difficulty
New Pronounceable
New Mixed Character String
New Unsentence-like capitalization
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New Symbol Start
1rj}{22OB12
OBrj12212}{
Filter
Rank by
Show/Hide Columns
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Change
Original Password
Permuted Password
Symbol start:
Number of Chunks:
Number of Characters:
Unsentence-like capitalization:
Mixed Character String:
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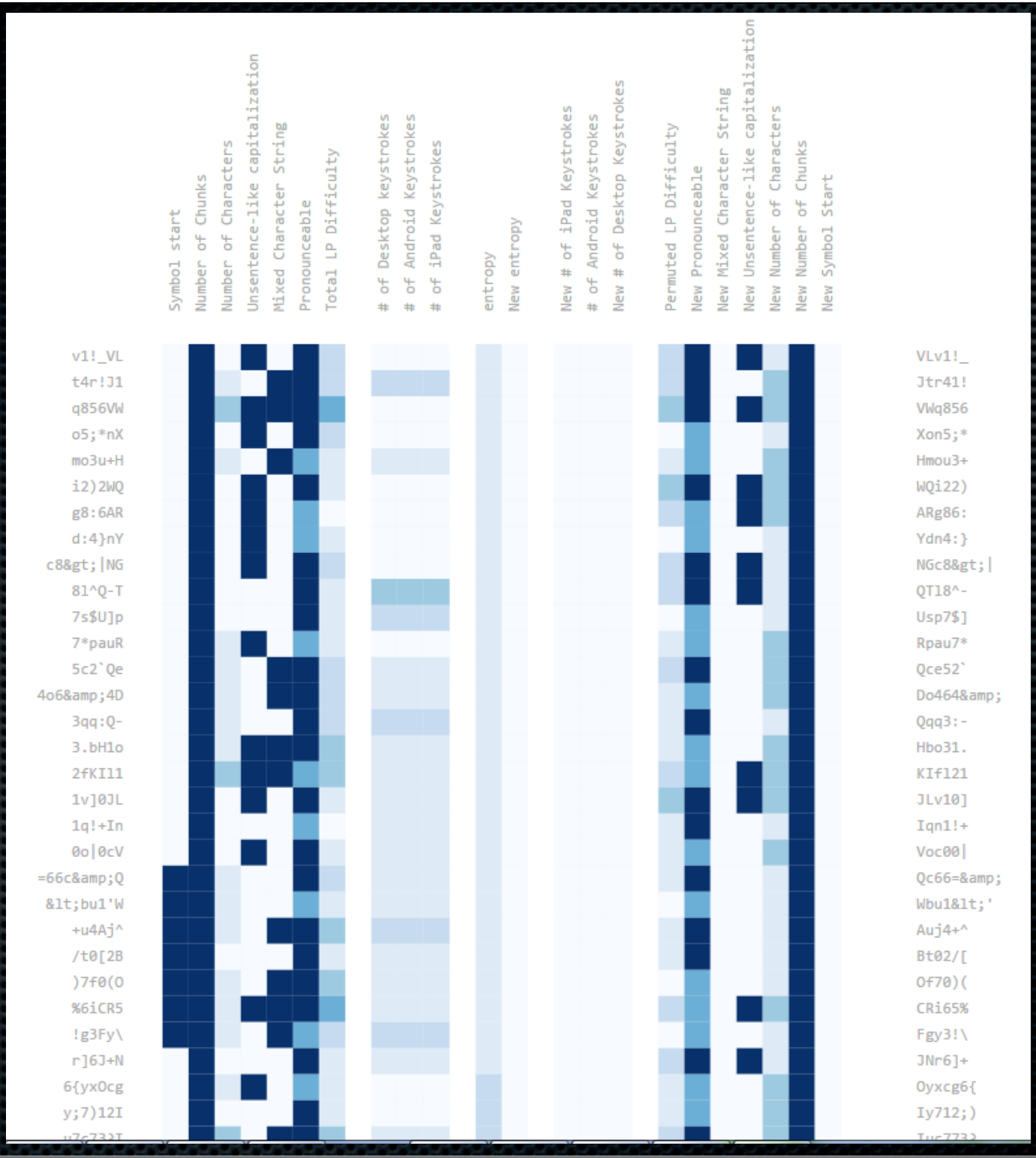
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Permuted LP Difficulty
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New Unsentence-like capitalization
New Number of Characters
New Number of Chunks
New Symbol Start
v1!_VL
t4r!J1
q856VW
o5;*nX
mo3u+H
i2)2WQ
g8:6AR
d:4}nY
c8>|NG
8l^Q-T
7s$U]p
7*pauR
5c2`Qe
4o6&4D
3qq:Q-
3.bH1o
2fKI11
1vJ0JL
1q!+In
0o|0cV
=66c&Q
<bu1'W
+u4Aj^
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VLv1!_
Jtr41!
VWq856
Xon5;*
Hmou3+
WQi22)
ARg86:
Ydn4:}
NGc8>|
QT18^-
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Qce52`
Do464&
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Hbo31.
KIfl21
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Voc00|
Qc66=&
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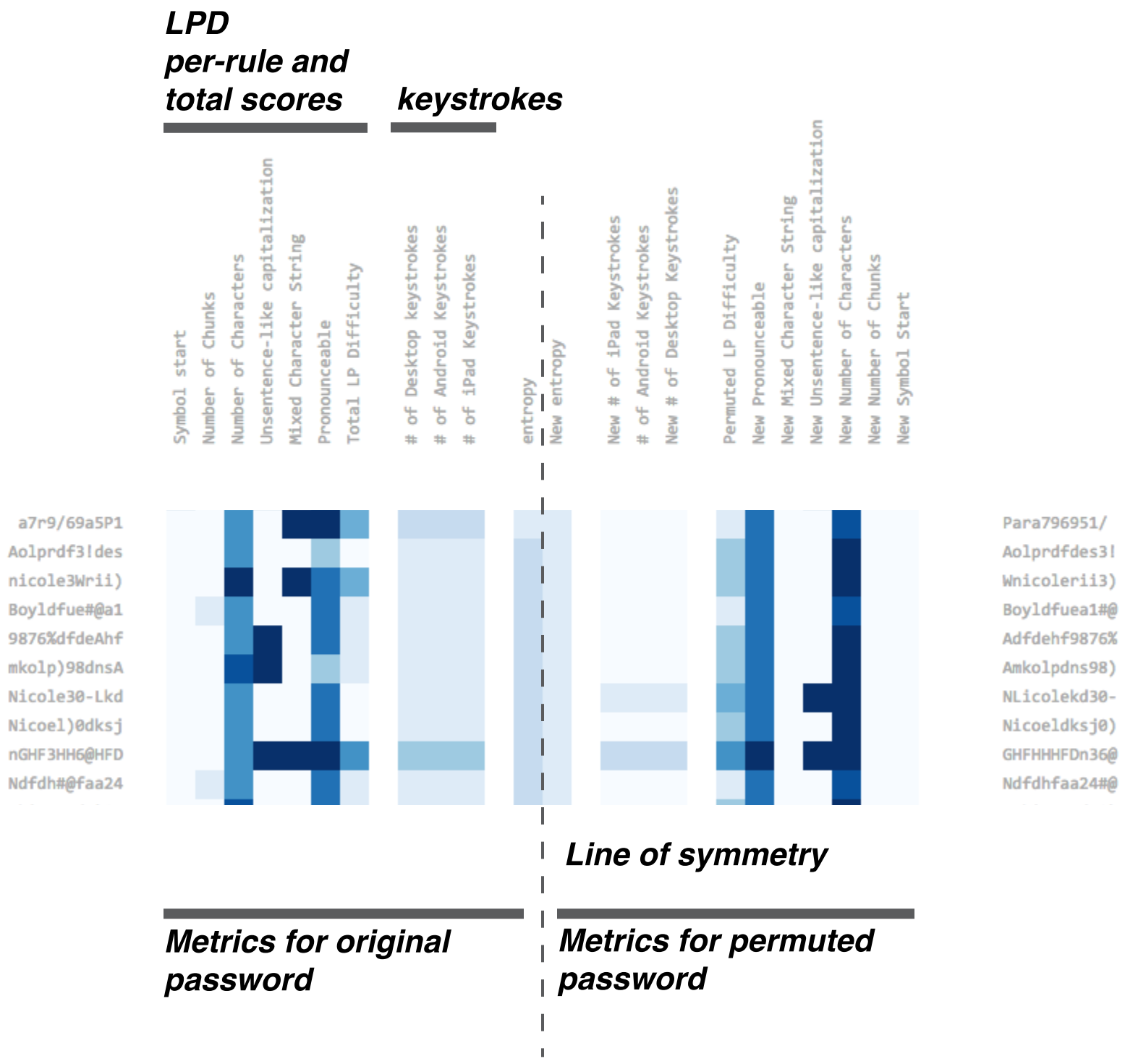
JNr6]+
Oyxcg6{
Iy712;)


LPD
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total scores
keystrokes
Symbol start
Number of Chunks
Number of Characters
Unsentence-like capitalization
Mixed Character String
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Total LP Difficulty
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New entropy
New # of iPad Keystrokes
# of Android Keystrokes
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Permuted LP Difficulty
New Pronounceable
New Mixed Character String
New Unsentence-like capitalization
New Number of Characters
New Number of Chunks
New Symbol Start
a7r9/69a5P1
Aolprdf3!des
nicole3Wrii)
Boyldfue#@a1
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mkolp)98dnsA
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Nicoel)0dksj
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Ndfdh#@faa24
Para796951/
Aolprdfdes3!
Wnicoleri3)
Boyldfuea1#@
Adfdehf9876%
Amkolpdns98)
NLicolekd30-
Nicoeldksj0)
GHFHHHFDn36@
Ndfdhfaa24#@
Line of symmetry
Metrics for original
password
Metrics for permuted
password

	Original Password	Permuted Password	
	q856VW	VWq856	
Symbol start:	0	0	Symbol start
Number of Chunks:	0	0	Number of Chunks
Number of Characters:	2	2	Number of Characters
Unsentence-like capitalization:	1	1	Unsentence-like capitalization
Mixed Character String:	1	0	Mixed Character String
Pronounceable:	0	0	Pronounceable
Total LP Difficulty:	4	3	Total LP Difficulty
# of Desktop keystrokes:	11	10	# of Desktop keystrokes
# of Android Keystrokes:	11	10	# of Android Keystrokes
# of iPad Keystrokes:	11	10	# of iPad Keystrokes
entropy:	39	33	entropy

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